Biodiversity considerations in the context of restoration science and practice

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Monitoring of restoration allows evaluation of implementation and effectiveness of interventions in meeting desired goals. The latter is of particular importance because it allows course corrections during the life of a project through adaptive management. When combined, monitoring data from many projects can shed light on best practices, inform planning decisions at larger scales, and contribute to scientific knowledge.

The incorporation of monitoring into restoration projects is not universal due to many factors, including costs, lack of technical expertise, and insufficient support. For example, during the 1990s in the United States, only 10% of >37,000 river restoration projects had any form of project monitoring and little information was available to assess the ecological effectiveness of restoration activities. Building support and providing funding for monitoring is key to both the future success of ecosystem restoration, and communicating success to stakeholders. The following concepts and considerations may be relevant in the implementation of monitoring activities:

Participatory and innovative techniques for monitoring

One challenge is to design monitoring so that it is efficient and engages stakeholders in local communities. Participatory monitoring can provide an important way to connect local and global priorities for forest restoration. Collaborating with stakeholders generally increases effectiveness and lowers costs of project monitoring. Restoration monitoring must be adapted to available resources and to specific needs. Not all monitoring requires sophisticated scientific procedures, and simple monitoring methods, such as establishing photo points and taking time-series photography can yield significant information. Modern technology, such as drones and remote sensing, are increasingly important in restoration monitoring and may help reduce monitoring costs over time.

Monitoring protocols

To assist practitioners, many monitoring protocols have been developed with appropriate indicators for the restoration of many types of ecosystems (e.g., butterflies and moths as indicators in Australian woodlands, oyster beds in the United States, soils as indicators in China, and tree community composition and vegetation structure as predictors of butterfly community composition during tropical rain forest restoration in Uganda). Restoration monitoring protocols have also been developed for large geographic regions, such as the Gulf of Mexico.

Recovery debt and restoration timescales

Monitoring can increase our understanding of ecosystem restoration, what it can accomplish, and its limitations. A review of 89 restoration assessments indicated that ecological restoration increased provision of biodiversity and ecosystem services by 44% and 25%, respectively, demonstrating that
ecosystem restoration can contribute to the recovery of biodiversity and ecosystem services, but cannot replace the conservation of intact ecosystems\textsuperscript{13}. Another study showed that even when full recovery is possible, considerable time may be required to re-establish biodiversity, and ecosystem functionality\textsuperscript{14}. This process is known as the ‘recovery debt’. In some cases, such as the restoration of deforested pasture lands to Australian tropical rain forest, up to 150 years may be required for full recovery\textsuperscript{15}. A meta-analysis of 221 forest landscapes identified the most important drivers of restoration success at both the local and landscape scale\textsuperscript{16}. Time since the initiation of restoration was most important for secondary forest but not for selectively logged forests. Forest landscape restoration was predicted to be most successful when previous disturbance is less intensive, and habitat is less fragmented on the landscape.

The importance of meta-analyses and reviews of monitoring outputs
Regional reviews of monitoring data can also be helpful to restoration planning. A review of more than 30 years of ecological restoration in the Atlantic Forest of Brazil revealed that many projects did not result in self-perpetuating forests\textsuperscript{17}. The reconstruction of a permanent forest with high diversity is feasible, but depends on the strategies applied and on the surrounding landscape. Although new techniques had been implemented (e.g., seed rain management and the promotion of natural regeneration), planting of many native species from different functional groups was the most common approach. Meta-analyses and reviews can provide a framework to evaluate emerging techniques, such as the use of mixed forest plantations (e.g., Eucalyptus-native species mixes in Brazil\textsuperscript{18}), in terms of both effectiveness and providing biodiversity and ecosystem services benefits.

References
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